## No Documents Found

No documents were found for your search (**5303138 or 5,303,138 or us5303138 or us5,303,138**). Please edit your search and try again. You may want to try one or more of the following:

- Check for spelling errors.
- Remove some search terms.
- Use more common search terms.
- If applicable, look for all dates.

Edit Search

About LEXIS-NEXIS | Terms and Conditions

1/1 PLUSPAT - (C) QUESTEL-ORBIT
PN - US5528482 A 19960618 [US5528482]
TI - (A) Low loss synchronous rectifier for application to clamped-mode power converters
PA - (A) AT & T CORP (US)
IN - (A) ROZMAN ALLEN F (US)
AP - US22502794 19940408 [1994US-0225027]
PR - US22502794 19940408 [1994US-0225027]
- US5491893 19930429 [1993US-0054918]
IC - (A) H02M-007/217
EC - H02M-003/335S
- H02M-003/335S2S
- H02M-007/217
PCL - ORIGINAL (O) : 363021060; CROSS-REFERENCE (X) : 327309000 363020000 363089000
DT - Corresponding document
CT - US5066900; US5126931; US5303138
- Principles of Solid-State Power Conversion, Tarter, 1st Ed, (1985), pp. 544-547.

"Current-Controlled Synchronous Rectrification" by B. Acker; C. R. Sullivan S. R. Sanders IEEE pp. 185-191, May 1994.

"High Efficiency DC--DC Converter" by I. D. Jitaru; G. Cocina. IEEE, pp. 638-644. May 1994.
STG - (A) United States patent
AB - A synchronous rectifier for use with a clamped-mode power converter uses in one embodiment a hybrid rectifier with a MOSFET rectifying device active in one first cyclic interval of the conduction/nonconduction sequence of the power switch and a second rectifying device embodied in one illustrative embodiment as a low voltage bipolar diode rectifying device active during an alternative interval to the first conduction/nonconduction interval. The gate drive to the MOSFET device is continuous at a constant level for substantially all of the second interval which enhances efficiency of the rectifier. The bipolar rectifier device may also be embodied as a MOSFET device. The subject rectifier may be used in both forward and flyback power converters.

1/1 LGST - (C) LEGSTAT
PN - US 5528482 [US5528482]
AP - US 225027/94 19940408 [1994US-0225027]
DT - US-P
ACT - 19940408 US/AE-A
APPLICATION DATA (PATENT)
{US 225027/94 19940408 [1994US-0225027]}
- 19940613 US/AS02
ASSIGNMENT OF ASSIGNOR'S INTEREST
AT&T CORP. 32 AVENUE OF THE AMERICAS NEW YORK, NY 10013-2412 * ROZMAN, ALLEN FRANK : 19940607
- 19960618 US/A
PATENT
- 19980721 US/RF
REISSUE APPLICATION FILED
980313
- 19991228 US/RF

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      REISSUE APPLICATION FILED
      19991027
UP  - 2000-04


1/1 CRXX - (C) CLAIMS/RRX
AN  - 2731188
PN  - 5,528,482 A  19960618  [US5528482]
PA  - AT&T Corp
PT  - E (Electrical)
ACT - 19980313  REISSUE REQUESTED
      Issue Date of O.G.: 19980721
      Reissue Request Number: 09/039106
      Examination Group responsible for Reissue process: 2111
      Reissue Patent Number: USRE36571

    - 19991027  REISSUE REQUESTED
      Issue Date of O.G.: 19991228
      Reissue Request Number: 09/429692
      Examination Group responsible for Reissue process: 2838

UP  - 1999-00
UACT- 1999-12-28

1/2 PAST - (C) PAST
AN  - 200007-001118
PN  - 5528482  A  [US5528482]
DT  - A (UTILITY)
OG  - 2000-02-15
CO  - RE
ACT - REISSUE PATENT
SH  - REISSUE PATENT
RL  - USRE36571

2/2 PAST - (C) PAST
AN  - 199829-001042
PN  - 5528482  A  [US5528482]
DT  - A (UTILITY)
OG  - 1998-07-21
CO  - REA
ACT - REISSUE APPLICATION FILED
SH  - REISSUE APPLICATION FILED
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4/39/1
DIALOG(R)File 345:Inpadoc/Fam.& Legal Stat


11722092
Basic Patent (No,Kind,Date): US 5303138 A 19940412 <No. of Patents: 010>
Patent Family:

| Patent No | Kind | Date | Applic No | Kind | Date | |
|---|---|---|---|---|---|---|
| EP 1052763 | A1 | 20001115 | EP 2000108230 | A | 19940420 | |
| EP 622891 | A2 | 19941102 | EP 94302791 | A | 19940420 | |
| EP 622891 | A3 | 19950111 | EP 94302791 | A | 19940420 | |
| JP 6327243 | A2 | 19941125 | JP 94113420 | A | 19940502 | |
| JP 2758137 | B2 | 19980528 | JP 94113420 | A | 19940502 | |
| US 5303138 | A | 19940412 | US 54918 | A | 19930429 | (BASIC) |
| US 5528482 | A | 19960618 | US 225027 | A | 19940408 | |
| US 5625541 | A | 19970429 | US 503684 | A | 19950718 | |
| US 5872705 | A | 19990216 | US 704056 | A | 19960828 | |
| US RE36571 | E | 20000215 | US 39106 | A | 19980313 | |

Priority Data (No,Kind,Date):
EP 94302791 A3 19940420
US 54918 A 19930429
US 225027 A 19940408
US 54918 A2 19930429
US 503684 A 19950718
US 225027 A2 19940408
US 704056 A 19960828
US 516423 B1 19950817
US 225027 A1 19940408
US 39106 A 19980313
US 225027 A5 19940408
US 54918 A1 19930429

PATENT FAMILY:
EUROPEAN PATENT OFFICE (EP)
Patent (No,Kind,Date): EP 1052763 A1 20001115
LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS (English; French; German)
Patent Assignee: AT & T CORP (US)
Author (Inventor): ROZMAN ALLEN FRANK (US)
Priority (No,Kind,Date): EP 94302791 A3 19940420; US 54918 A 19930429
Applic (No,Kind,Date): EP 2000108230 A 19940420
Designated States: (National) DE; FR; GB
IPC: * H02M-003/335
Derwent WPI Acc No: * G 94-117846; G 96-300133; G 97-258430; G 99-166852
Language of Document: English
Patent (No,Kind,Date): EP 622891 A2 19941102
LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS. (English; French; German)
Patent Assignee: AT & T CORP (US)
Author (Inventor): ROZMAN ALLEN FRANK (US)
Priority (No,Kind,Date): US 54918 A 19930429
Applic (No,Kind,Date): EP 94302791 A 19940420
Designated States: (National) DE; FR; GB
IPC: * H02M-007/217; H02M-003/335
Derwent WPI Acc No: * G 94-117846; G 96-300133; G 97-258430; G

99-166852
Language of Document: English
Patent (No,Kind,Date): EP 622891 A3 19950111
LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS. (English; French; German)
Patent Assignee: AT & T CORP (US)
Author (Inventor): ROZMAN ALLEN FRANK (US)
Priority (No,Kind,Date): US 54918 A 19930429
Applic (No,Kind,Date): EP 94302791 A 19940420
Designated States: (National) DE; FR; GB
IPC: * H02M-007/217; H02M-003/335
Derwent WPI Acc No: * G 94-117846; G 96-300133; G 97-258430; G 99-166852
Language of Document: English

EUROPEAN PATENT OFFICE (EP)
Legal Status (No,Type,Date,Code,Text):

| | | | | |
|---|---|---|---|---|
| EP 622891 | P | 19930429 | EP AA | PRIORITY (PATENT APPLICATION) (PRIORITAET (PATENTANMELDUNG)) US 54918 A 19930429 |
| EP 622891 | P | 19940420 | EP AE | EP-APPLICATION (EUROPAEISCHE ANMELDUNG) EP 94302791 A 19940420 |
| EP 622891 | P | 19941102 | EP AK | DESIGNATED CONTRACTING STATES IN AN APPLICATION WITHOUT SEARCH REPORT (IN EINER ANMELDUNG OHNE RECHERCHENBERICHT BENANNTE VERTRAGSSTAATEN) DE FR GB |
| EP 622891 | P | 19941102 | EP A2 | PUBLICATION OF APPLICATION WITHOUT SEARCH REPORT (VEROEFFENTLICHUNG DER ANMELDUNG OHNE RECHERCHENBERICHT) |
| EP 622891 | P | 19950111 | EP AK | DESIGNATED CONTRACTING STATES IN A SEARCH REPORT (IN EINEM RECHERCHENBERICHT BENANNTE VERTRAGSSTAATEN) DE FR GB |
| EP 622891 | P | 19950111 | EP A3 | SEPARATE PUBLICATION OF THE SEARCH REPORT (ART. 93) (GESONDERTE VEROEFFENTLICHUNG DES RECHERCHENBERICHTS (ART. 93)) |
| EP 622891 | P | 19950830 | EP 17P | REQUEST FOR EXAMINATION FILED (PRUEFUNGSANTRAG GESTELLT) 950630 |
| EP 622891 | P | 19970423 | EP 17Q | FIRST EXAMINATION REPORT (ERSTER PRUEFUNGSBESCHEID) 970307 |
| EP 622891 | P | 20000607 | EP RAHF | DIVISIONAL APPLICATION (ART 76) IN: (CORRECTION) (TEILANMELDUNG (ART. 76) IN: (KORR.)) EP 2000108230 A 20000414 |
| EP 622891 | P | 20001115 | EP AH | DIVISIONAL APPLICATION (ART. 76) IN: (TEILANMELDUNG (ART. 76) IN:) EP 1052763 P |
| EP 1052763 | P | 19930429 | EP AA | PRIORITY (PATENT APPLICATION) (PRIORITAET (PATENTANMELDUNG)) |

US 54918 A 19930429

EP 1052763 P 19940420 EP AA DIVIDED OUT OF (AUSSCHEIDUNG AUS)
EP 94302791 A3 19940420

EP 1052763 P 19940420 EP AE EP-APPLICATION (EUROPAEISCHE ANMELDUNG)
EP 2000108230 A 19940420

EP 1052763 P 20001115 EP AC DIVISIONAL APPLICATION (ART. 76) OF: (TEILANMELDUNG (ART. 76) AUS:)
EP 622891 P

EP 1052763 P 20001115 EP AK DESIGNATED CONTRACTING STATES IN AN APPLICATION WITH SEARCH REPORT: (IN EINER ANMELDUNG BENANNTE VERTRAGSSTAATEN)

DE FR GB

EP 1052763 P 20001115 EP A1 PUBLICATION OF APPLICATION WITH SEARCH REPORT (VEROEFFENTLICHUNG DER ANMELDUNG MIT RECHERCHENBERICHT)

EP 1052763 P 20001115 EP 17P REQUEST FOR EXAMINATION FILED (PRUEFUNGSANTRAG GESTELLT)
20000426

JAPAN (JP)
Patent (No,Kind,Date): JP 6327243 A2 19941125
POWER CONVERTER (English)
Patent Assignee: AMERICAN TELEPHONE & TELEGRAPH
Author (Inventor): AREN FURANKU ROZUMAN
Priority (No,Kind,Date): US 54918 A 19930429
Applic (No,Kind,Date): JP 94113420 A 19940502
IPC: * H02M-003/28
Language of Document: Japanese
Patent (No,Kind,Date): JP 2758137 B2 19980528
Patent Assignee: EI TEI ANDO TEI CORP
Author (Inventor): AREN FURANKU ROZUMAN
Priority (No,Kind,Date): US 54918 A 19930429
Applic (No,Kind,Date): JP 94113420 A 19940502
IPC: * H02M-003/28
Language of Document: Japanese

UNITED STATES OF AMERICA (US)
Patent (No,Kind,Date): US 5303138 A 19940412
LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS (English)
Patent Assignee: AT & T BELL LAB (US)
Author (Inventor): ROZMAN ALLEN F (US)
Priority (No,Kind,Date): US 54918 A 19930429
Applic (No,Kind,Date): US 54918 A 19930429
National Class: * 363021000; 363020000; 363089000; 363097000; 363127000
IPC: * H02M-003/335; H02M-007/217
Derwent WPI Acc No: ; G 94-117846
Language of Document: English
Patent (No,Kind,Date): US 5528482 A 19960618
LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS (English)
Patent Assignee: AT & T CORP (US)

Author (Inventor): ROZMAN ALLEN F (US)
Priority (No,Kind,Date): US 225027 A 19940408; US 54918 A2 19930429
Applic (No,Kind,Date): US 225027 A 19940408
Addnl Info: 5303138 19940412 Patented
National Class: * 363021000; 363020000; 363089000; 327309000
IPC: *. H02M-007/217
Derwent WPI Acc No: * G 94-117846; G 96-300133; G 97-258430; G 99-166852; G 96-300133
Language of Document: English

Patent (No,Kind,Date): US 5625541 A 19970429
LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS (English)
Patent Assignee: LUCENT TECHNOLOGIES INC (US)
Author (Inventor): ROZMAN ALLEN F (US)
Priority (No,Kind,Date): US 503684 A 19950718; US 225027 A2 19940408; US 54918 A2 19930429
Applic (No,Kind,Date): US 503684 A 19950718
Addnl Info: 5528482 Patented; 5303138 Patented
National Class: * 363021000; 363020000; 363089000; 363147000; 327309000
IPC: * H02M-007/217; H02M-003/335
Derwent WPI Acc No: * G 94-117846; G 96-300133; G 97-258430; G 99-166852; G 97-258430
Language of Document: English

Patent (No,Kind,Date): US 5872705 A 19990216
LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS (English)
Patent Assignee: LUCENT TECHNOLOGIES INC (US)
Author (Inventor): LOFTUS JR THOMAS PATRICK (US); ROZMAN ALLEN FRANK (US)
Priority (No,Kind,Date): US 704056 A 19960828; US 516423 B1 19950817; US 225027 A1 19940408; US 54918 A2 19930429
Applic (No,Kind,Date): US 704056 A 19960828
Addnl Info: 5528482 19960618 Patented; 5303138 19940412 Patented
National Class: * 363021000; 363089000; 363097000; 363127000; 363131000
IPC: * H02M-003/335
Derwent WPI Acc No: ; G 99-166852
Language of Document: English

Patent (No,Kind,Date): US RE36571 E 20000215
LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS (English)
Patent Assignee: LUCENT TECHNOLOGIES INC (US)
Author (Inventor): ROZMAN ALLEN FRANK (US)
Priority (No,Kind,Date): US 39106 A 19980313; US 225027 A5 19940408; US 54918 A1 19930429
Applic (No,Kind,Date): US 39106 A 19980313
Addnl Info: 5528482 19960618 Reissue of; 5303138 19940412 Patented
National Class: * 363021000; 363020000; 363089000; 327309000
IPC: * H02M-007/217
Derwent WPI Acc No: * G 94-117846; G 96-300133; G 97-258430; G 99-166852
Language of Document: English

UNITED STATES OF AMERICA (US)
Legal Status (No,Type,Date,Code,Text):

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| US 36571 | E | 19930429 | US AA | PRIORITY |
| | | | | US 54918 A1 19930429 |
| US 36571 | E | 19940408 | US AA | PRIORITY |
| | | | | US 225027 A5 19940408 |
| US 36571 | E | 19980313 | US AE | APPLICATION DATA (PATENT) |
| | | | | (APPL. DATA (PATENT)) |
| | | | | US 39106 A 19980313 |
| US 36571 | E | 20000215 | US E | REISSUE |
| US 5303138 | P | 19930429 | US AE | APPLICATION DATA (PATENT) |
| | | | | (APPL. DATA (PATENT)) |
| | | | | US 54918 A 19930429 |
| US 5303138 | P | 19930429 | US AS02 | ASSIGNMENT OF ASSIGNOR'S |
| | | | | INTEREST |
| | | | | AMERICAN TELEPHONE AND TELEGRAPH COMPANY 37 AVENUE OF THE AMERICAS NEW YORK, NY ; ROZMAN, ALLEN, F. : 19930421 |
| US 5303138 | P | 19940412 | US A | PATENT |
| US 5528482 | P | 19930429 | US AA | PRIORITY |
| | | | | US 54918 A2 19930429 |
| US 5528482 | P | 19940408 | US AE | APPLICATION DATA (PATENT) |
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| | | | | US 225027 A 19940408 |
| US 5528482 | P | 19940613 | US AS02 | ASSIGNMENT OF ASSIGNOR'S |
| | | | | INTEREST |
| | | | | AT&T CORP. 32 AVENUE OF THE AMERICAS NEW YORK, NY 10013-2412 ; ROZMAN, ALLEN FRANK : 19940607 |
| US 5528482 | P | 19960618 | US A | PATENT |
| US 5528482 | P | 19980721 | US RF | REISSUE APPLICATION FILED |
| | | | | (REISSUE APPL. FILED) |
| | | | | 980313 |
| US 5528482 | P | 19991228 | US RF | REISSUE APPLICATION FILED |
| | | | | (REISSUE APPL. FILED) |
| | | | | 19991027 |
| US 5625541 | P | 19930429 | US AA | PRIORITY |
| | | | | US 54918 A2 19930429 |
| US 5625541 | P | 19940408 | US AA | PRIORITY |
| | | | | US 225027 A2 19940408 |
| US 5625541 | P | 19950718 | US AE | APPLICATION DATA (PATENT) |
| | | | | (APPL. DATA (PATENT)) |
| | | | | US 503684 A 19950718 |
| US 5625541 | P | 19950718 | US AS02 | ASSIGNMENT OF ASSIGNOR'S |
| | | | | INTEREST |
| | | | | AT&T IPM CORPORATION 2333 PONCE DE LEON BLVD. CORAL GABLES, FLORIDA 33134 ; ROZMAN, ALLEN FRANK : 19950711 |
| US 5625541 | P | 19970429 | US A | PATENT |
| US 5625541 | P | 19980428 | US CC | CERTIFICATE OF CORRECTION |
| US 5872705 | P | 19930429 | US AA | PRIORITY |
| | | | | US 54918 A2 19930429 |
| US 5872705 | P | 19940408 | US AA | PRIORITY |
| | | | | US 225027 A1 19940408 |
| US 5872705 | P | 19950817 | US AA | PRIORITY |
| | | | | US 516423 B1 19950817 |
| US 5872705 | P | 19960828 | US AE | APPLICATION DATA (PATENT) |
| | | | | (APPL. DATA (PATENT)) |
| | | | | US 704056 A 19960828 |

| | | | | |
|---|---|---|---|---|
| US 5872705 | P | 19961113 | US AS02 | ASSIGNMENT OF ASSIGNOR'S INTEREST<br>LUCENT TECHNOLOGIES, INC. P.O. BOX 636 600 MOUNTAIN AVENUE MURRAY HILL, NEW JERS ;<br>ROZMAN, ALLEN FRANK : 19961105 |
| US 5872705 | P | 19990216 | US A | PATENT |

1/1 PLUSPAT - (C) QUESTEL-ORBIT

PN - USRE36571 E 20000215 [USRE36571]

TI - (E) Low loss synchronous rectifier for application to clamped-mode power converters

PA - (E) LUCENT TECHNOLOGIES INC (US)

IN - (E) ROZMAN ALLEN FRANK (US)

AP - US3910698 19980313 [1998US-0039106]

PR - US3910698 19980313 [1998US-0039106]
- US22502794 19940408 [1994US-0225027]
- US5491893 19930429 [1993US-0054918]

IC - (E) H02M-007/217

EC - H02M-003/335S
- H02M-003/335S2S

PCL - ORIGINAL (O) : 363021060; CROSS-REFERENCE (X) : 327309000 363020000 363021140 363089000

DT - Basic

CT - US3989995; US4441146; US4618919; US4716514; US4788634; US4809148; US4857822; US4870555; US4903189; US4931716; US4959764; US4975821; US5066900; US5099406; US5126651; US5126931; US5179512; US5231563; US5268830; US5274543; US5282123; US5291382; US5303138; US5353212; US5434768; US5535112; US5541828; EP0058400 A2; EP0289196 A2; EP0428377 A2; EP0474471 A2; EP0508664 A1; SU892614; WO8302858; WO8908347

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"Practical Application of Mosfet Synchronous Rectifiers" by James Blanc; 1991 IEEE; pp. 495-501.

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"High Power and High Switching Frequency DC-to-DC Converter using Saturable Inductor Commutation and Switched Snubber" by Koosuke Harada and Hiroshi Sakamoto; 1991 IEEE; pp. 148-154.

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"Current Controlled Synchronous Rectification", by B. Acker, C. Cir Sullivan, S.R. Sanders, IEEE pp. 185-181, May 1994.

"High Efficiency DC-DC Converter" by I.D. Jitaru, Gicocina, IEEE, pp. 638-644 May 1994.

STG - (E) Reissue

AB - A synchronous rectifier for use with a clamped-mode power converter uses in one embodiment a hybrid rectifier with a MOSFET rectifying device active in one first cyclic internal of the conduction/nonconduction sequence of the power switch and a second rectifying device embodied in one illustrative embodiment as a low voltage bipolar diode rectifying device active during an alternative interval to the first conduction/nonconduction interval. The gate drive to the MOSFET device is continuous at a constant level for substantially all of the second interval which enhances efficiency of the rectifier. The bipolar rectifier device may also be embodied as a MOSFET device. The subject rectifier may be used in both forward and flyback power converters.

UP - 2000-10

1/1 PAST - (C) PAST
AN - 200007-001118
PN - 5528482 A [US5528482]
DT - A (UTILITY)
OG - 2000-02-15
CO - RE
ACT - REISSUE PATENT
SH - REISSUE PATENT
RL - USRE36571

Source: All Sources : Area of Law - By Topic : Patent Law : Patents : U.S. Patents : **Reissue Patents**
Terms: **patno is 36571** (Edit Search)

*Pat. No. 36571, **

RE **36,571**

◆ GET 1st DRAWING SHEET OF 4

Feb. 15, 2000

Low loss synchronous rectifier for application to clamped-mode power converters

**INVENTOR:** Rozman, Allen Frank, Richardson, Texas

**ASSIGNEE-AT-ISSUE:** Lucent Technologies Inc., Murray Hill, New Jersey (02)

**APPL-NO:** 39,106

**FILED:** Mar. 13, 1998

**REL-US-DATA:**

Reissue of

| | |
|---|---|
| Patent No.: | 5,528,482 |
| Issued: | Jun. 18, 1996 |
| Appl. No.: | 8-225,027 |
| Filed: | Apr. 8, 1994 |

Continuation of Application No. 8-054,918, Apr. 29, 1993 now patented 5,303,138 Apr. 12, 1994

**INT-CL:** [7] H02M 7#217

**US-CL:** 363#21; 363#20; 363#89; 327#309

**CL:** 363;327

**SEARCH-FLD:** 363#20, 21, 89, 97, 126, 127; 327#309

**REF-CITED:**

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| 4,618,919 | 10/1986 | * | Martin, Jr. | 363#21 |
| 4,716,514 | 12/1987 | * | Patel | 363#127 |
| 4,788,634 | 11/1988 | * | Schlecht et al. | 363#21 |
| 4,809,148 | 2/1989 | * | Barn | 363#20 |

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Sources

All Sources : Area of Law - By Topic : Patent Law : Multi-Source Groups : **Patent Cases from Federal Courts and Administrative Materials**

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Terms and Connectors | Natural Language

re w/1 36571 or re36571 or usre36571 or re w/1 36,571 or re36,571 or usre36,571

Search

Use connectors to show relation of terms (cat or feline, jane w/3 doe) more...

Suggest Words and Concepts for Entered Terms

Restrict Search Using Document Segments

Optional: Restrict by Date

No Date Restrictions | From | To

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Source: All Sources : Area of Law - By Topic : Patent Law : Patents : U.S. Patents : **Utility Patents**
Terms: **patno is 5528482** (Edit Search)

*Pat. No. 5,528,482, **

**5,528,482**

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Jun. 18, 1996

Low loss synchronous rectifier for application to clamped-mode power converters

**REISSUE:** This Patent was reissued on Feb. 15, 2000 as Reissue Patent Re 36,571.

Reissue Application filed Oct. 27, 1999 (O.G. Dec. 28, 1999) Ex. Gp.: 2838; Re. S.N. 09/429,692

Reissue Application filed Mar. 13, 1998 (O.G. Jul. 21, 1998) Ex. Gp.: 2111; Re. S.N. 09/039,106

**INVENTOR:** Rozman, Allen F., Richardson, Texas

**ASSIGNEE-AT-ISSUE:** AT&T Corp., Murray Hill, New Jersey (02)

**APPL-NO:** 225,027

**FILED:** Apr. 8, 1994

**REL-US-DATA:**
Continuation-in-part of Ser. No. 54,918, Apr. 29, 1993 now patented 5,303,138 Apr. 12, 1994

**INT-CL:** [6] H02M 7#217

**US-CL:** 327#309; 222#87;

**CL:** 327;222;

**SEARCH-FLD:** 363#20, 21, 89, 97, 126, 127

**REF-CITED:**

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|---|---|---|---|---|
| 5,066,900 | 11/1991 | * | Bassett | 323#224 |
| 5,126,931 | 6/1992 | * | Jitaru | 363#21 |
| 5,303,138 | 4/1994 | * | Rozman | 363#21 |

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"High Efficiency DC-DC Converter" by I. D. Jitaru; G. Cocina. IEEE, pp. 638-644. May 1994.

**PRIM-EXMR:** Wong, Peter S.

**ASST-EXMR:** Riley, Shawn

**LEGAL-REP:** Pacher; Eugen E.

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*PR Newswire, July 5, 1988*


PR Newswire

July 5, 1988, Tuesday

**DISTRIBUTION:** TO BUSINESS DESK AND ENTERTAINMENT EDITOR

**LENGTH:** 650 words

**HEADLINE:** 'COMING TO AMERICA' RECORD-BREAKING SIX-DAY GROSS IS $28.4M

**DATELINE:** HOLLYWOOD, July 5

**BODY:**

On Wednesday, June 29, the film grossed $3,780,155; on Thursday, June 30, $3,224,922; on Friday, July 1, $**5,528,482;** on Saturday, July 2, $6,488,578; on Sunday, July 3, $5,904,041; and on Monday, July 4, the gross was $3,483,319.

In New York City, playing on 128 screens, "Coming To ...

monetary figure -Not Patent No.

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Date/Time: Wednesday, May 2, 2001 - 10:53 AM EDT

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1/1 PLUSPAT - (C) QUESTEL-ORBIT

PN - US5303138 A 19940412 [US5303138]

TI - (A) Low loss synchronous rectifier for application to clamped-mode power converters

PA - (A) AT & T BELL LAB (US)

IN - (A) ROZMAN ALLEN F (US)

AP - US5491893 19930429 [1993US-0054918]

PR - US5491893 19930429 [1993US-0054918]

IC - (A) H02M-003/335 H02M-007/217

EC - H02M-003/335S
- H02M-003/335S2S
- H02M-007/217

PCL - ORIGINAL (O) : 363021060; CROSS-REFERENCE (X) : 363020000 363089000 363097000 363127000

DT - Basic

CT - US4716514; US4788634; US4857822; US4870555; US4903189; US5066900; US5099406; US5126931; EP0508664

- "Improving Power Supply Efficiency with MOSFET Synchronous Rectifiers", R. Kagan, M. Chi, Proceedings of PowerCon 9, 1982, pp. 1-5.

"MOSFETs Move in on Low Voltage Rectification", M. alexander, R. Blanchard, R. Severns, Applications Handbook, Siliconix Technical Article, 1984, Siliconix Inc., pp. 569-580.

"A MOSFET Resonant Synchronous Rectifier for High-Frequency DC/DC Converters" W. Tabisz, F. Lee, D. Chen, PESC Proceedings, 1990, pp. 769-779.

"A Simple and Efficient Synchronous Rectifier for Forward DC-DC Converters", N. Murakami, H. Namiki, K. Sakakibara, T. Yachi, APEC Proceedings, 1993 pp. 463-468.

"Practical Application of MOSFET Synchronous Rectifiers", J. Blanc, Intelec Proceedings, 1991, pp. 495-501.

"High Power SMPS Require Intrinsic Reliability", PCI Proceedings, B. Carsten Sep. 14, 1981, pp. 118-133.

"Constant Frequency Forward Converter With Resonant Transitions", I. Jitaru, HEPC '91 Proceedings, pp. 282-292.

STG - (A) United States patent

AB - A synchronous rectifier for use with a clamped-mode power converter uses in one embodiment a hybrid rectifier with a MOSFET rectifying device active in one first cyclic interval of the conduction/nonconduction sequence of the power switch and a second rectifying device embodied in one illustrative embodiment as a low voltage bipolar diode rectifying device active during an alternative interval to the first conduction/nonconduction interval. The gate drive to the MOSFET device is continuous at a constant level for substantially all of the second interval which enhances efficiency of the rectifier. The bipolar rectifier device may also be embodied as a MOSFET device. The subject rectifier may be used in both forward and flyback power converters.

1/1 LGST - (C) LEGSTAT

PN - US 5303138 [US5303138]

```
AP  - US 54918/93  19930429  [1993US-0054918]
DT  - US-P
ACT - 19930429  US/AE-A
      APPLICATION DATA (PATENT)
      {US 54918/93  19930429  [1993US-0054918]}
    - 19930429  US/AS02
      ASSIGNMENT OF ASSIGNOR'S INTEREST
      AMERICAN TELEPHONE AND TELEGRAPH COMPANY 37 AVENUE OF THE AMERICAS NEW
      YORK, NY * ROZMAN, ALLEN, F. : 19930421
    - 19940412  US/A
      PATENT
UP  - 1999-16
```

*Pat. No. 5,303,138, **

**5,303,138**

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Apr. 12, 1994

Low loss synchronous rectifier for application to clamped-mode power converters

**INVENTOR:** Rozman, Allen F., Richardson, Texas

**ASSIGNEE-AT-ISSUE:** AT&T Bell Laboratories, Murray Hill, New Jersey (02)

**APPL-NO:** 54,918

**FILED:** Apr. 29, 1993

**INT-CL:** [5] H02M 3#335; H02M 7#217

**US-CL:** 363#21; 363#20; 363#89; 363#97; 363#127;

**CL:** 363;

**SEARCH-FLD:** 363#20, 21, 97, 89, 126, 127; #; H02#M7155; H02#M7217; H02#M3335

**REF-CITED:**

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| 5,126,931 | 6/1992 | * | Jitaru | 363#21 |

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"A Simple and Efficient Synchronous Rectifier for Forward DC-DC Converters", N. Murakami, H. Namiki, K. Sakakibara, T. Yachi, APEC Proceedings, 1993 pp. 463-468.
"Practical Application of MOSFET Synchronous Rectifiers", J. Blanc, Intelec Proceedings, 1991, pp. 495-501.

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10D11

May 2, 2001

Re: **09/429,692 (US RE36,571, US 5,528,482, US 5,303,138)**

Dear Examiner Riley,

Attached are the requested litigation search results.

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No Litigation cases were found.

Thank you for using EIC2800!

Paul Schulwitz
308-6559
CP4-9C18

USOORE36571E

# United States Patent [19]

**Rozman**

[11] E **Patent Number: Re. 36,571**

[45] **Reissued Date of Patent: *Feb. 15, 2000**

[54] **LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS**

[75] Inventor: **Allen Frank Rozman**, Richardson, Tex.

[73] Assignee: **Lucent Technologies Inc.**, Murray Hill, N.J.

[ * ] Notice: This patent is subject to a terminal disclaimer.

[21] Appl. No.: **09/039,106**

[22] Filed: **Mar. 13, 1998**

**Related U.S. Patent Documents**

Reissue of:

[64] Patent No.: **5,528,482**
Issued: **Jun. 18, 1996**
Appl. No.: **08/225,027**
Filed: **Apr. 8, 1994**

U.S. Applications:

[63] Continuation of application No. 08/054,918, Apr. 29, 1993, Pat. No. 5,303,138.

[51] **Int. Cl.**$^{7}$ ..................................................... **H02M 7/217**

[52] **U.S. Cl.** ................................ **363/21**; 363/20; 363/89; 327/309

[58] **Field of Search** ................................ 363/20, 21, 89, 363/97, 126, 127; 327/309

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| 4,716,514 | 12/1987 | Patel | 363/127 |
| 4,788,634 | 11/1988 | Schlecht et al. | 363/21 |

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*Primary Examiner*—Shawn Riley

[57] **ABSTRACT**

A synchronous rectifier for use with a clamped-mode power converter uses in one embodiment a hybrid rectifier with a MOSFET rectifying device active in one first cyclic internal of the conduction/nonconduction sequence of the power switch and a second rectifying device embodied in one illustrative embodiment as a low voltage bipolar diode rectifying device active during an alternative interval to the first conduction/nonconduction interval. The gate drive to the MOSFET device is continuous at a constant level for substantially all of the second interval which enhances efficiency of the rectifier. The bipolar rectifier device may also be embodied as a MOSFET device. The subject rectifier may be used in both forward and flyback power converters.

**60 Claims, 4 Drawing Sheets**

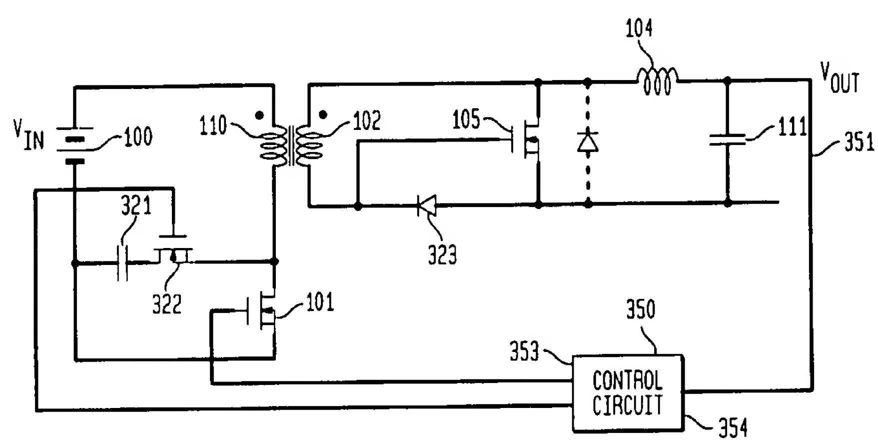

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FIG. 1
(PRIOR ART)

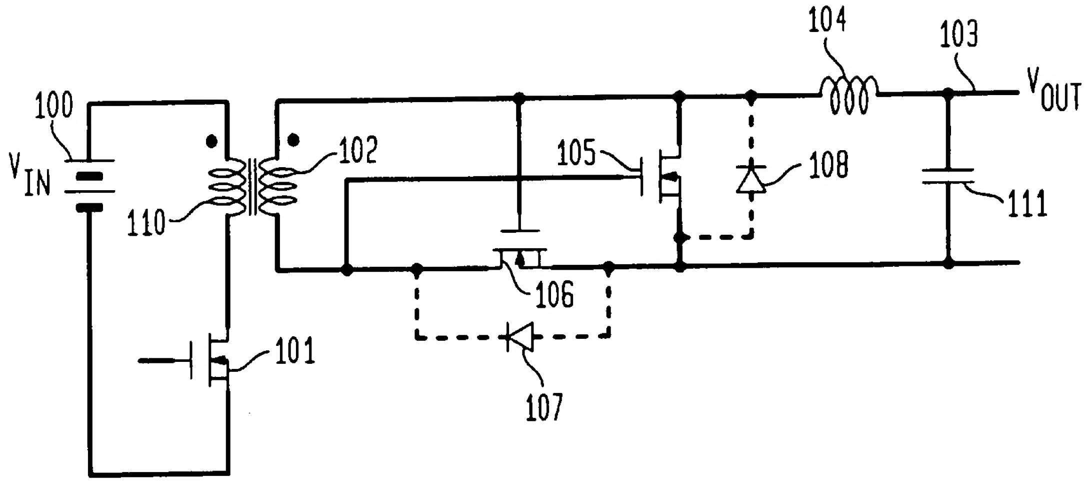



FIG. 2
(PRIOR ART)

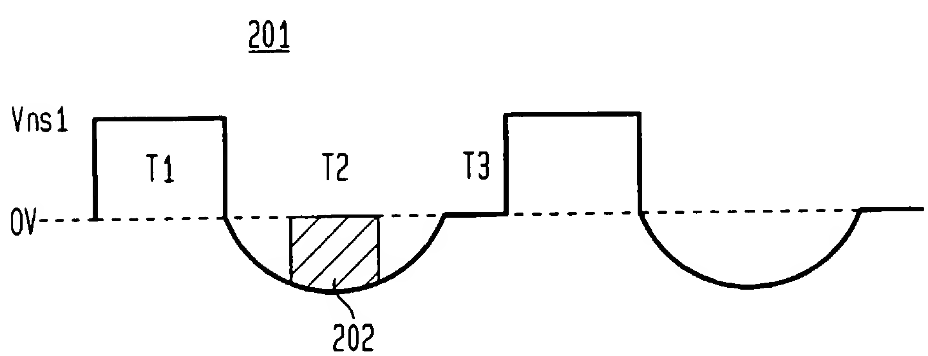


FIG. 3

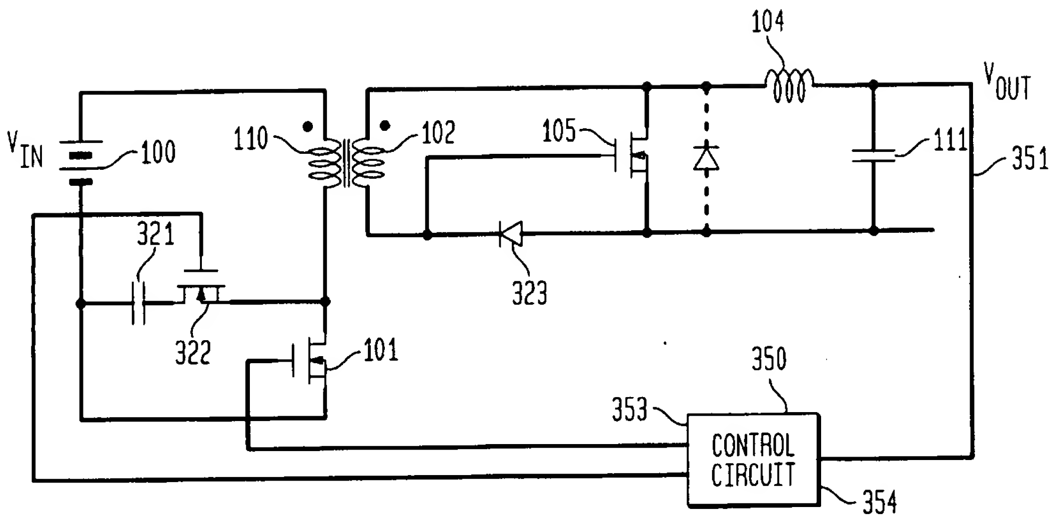

104
$V_{OUT}$
$V_{IN}$
100
110
102
105
111
351
321
323
322
101
350
353
CONTROL CIRCUIT
354

FIG. 4

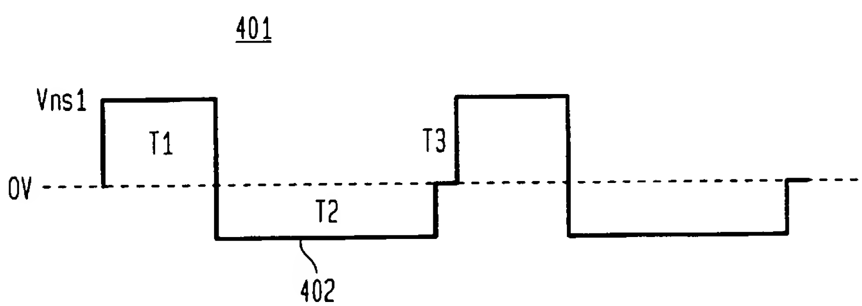

401
Vns1
T1
T3
0V
T2
402

FIG. 5

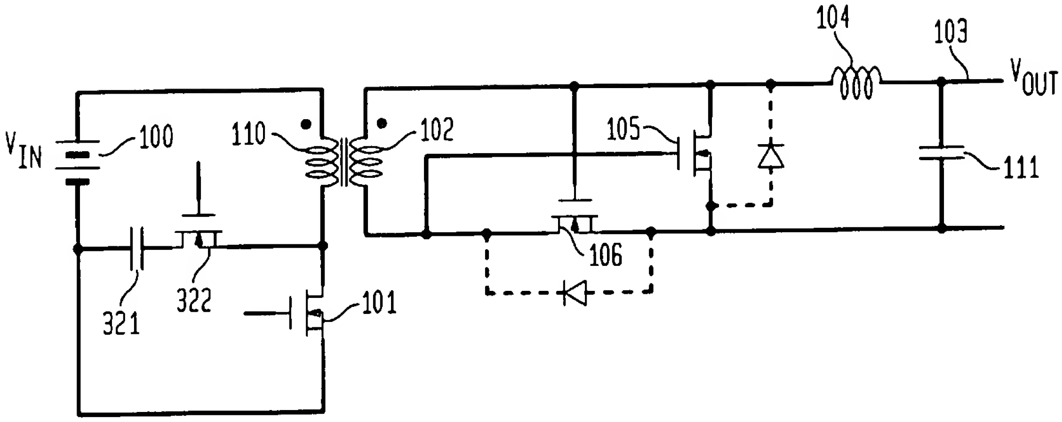

104
103
$V_{OUT}$
$V_{IN}$
100
110
102
105
111
106
321
322
101

FIG. 6

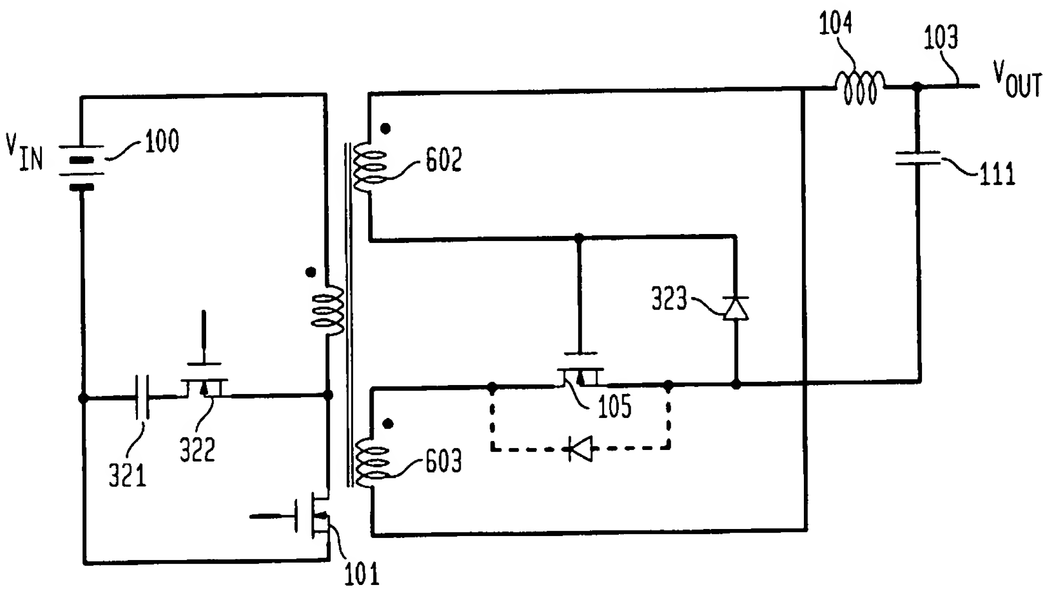

104
103
$V_{OUT}$
$V_{IN}$
100
602
111
323
105
321
322
603
101

FIG. 7

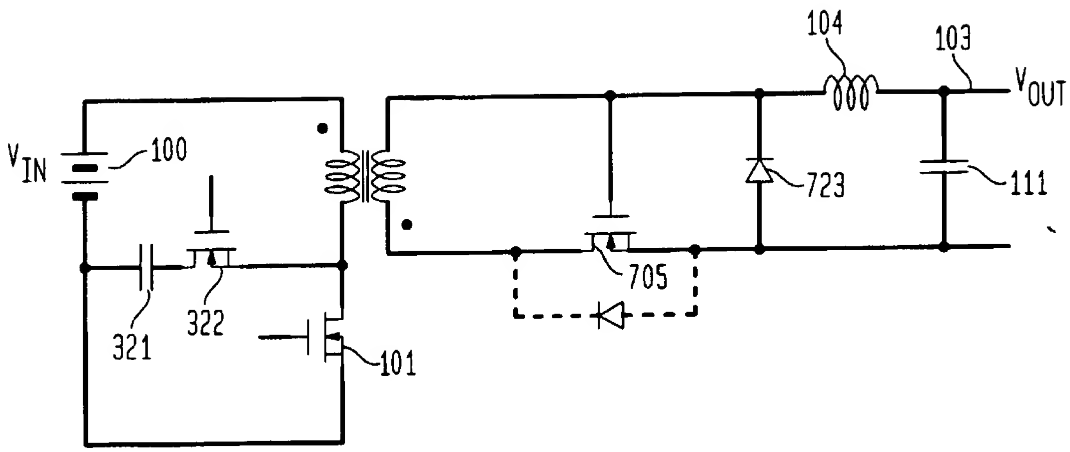
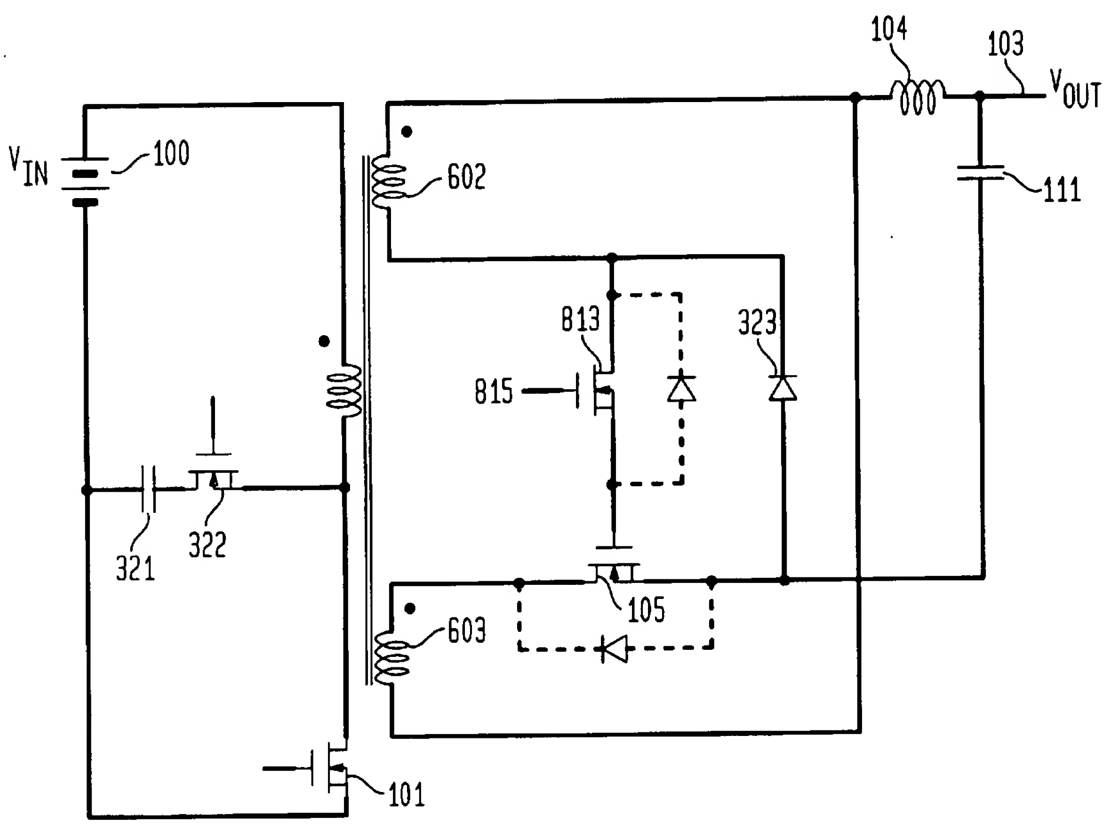

104
103
$V_{OUT}$
$V_{IN}$
100
723
111
705
321
322
101

FIG. 8


104
103
$V_{OUT}$
$V_{IN}$
100
602
111
813
323
815
321
322
105
603
101

# LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS

**Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.**

This application is a [continuation in part] *reissue of Ser. No. 08/225,027 filed Apr. 8, 1994 U.S. Pat. No. 5,528,482 and a continuation* of application Ser. No. 08/054,918 filed on Apr. 29, 1993 now issued as U.S. Pat. No. 5,303,138 on Apr. 12, 1994.

## FIELD OF THE INVENTION

This invention relates to switching type power converters and in particular to forward and flyback converters having a clamp-mode topology.

## BACKGROUND OF THE INVENTION

Self synchronized rectifiers refer to rectifiers using MOSFET rectifying devices having control terminals which are driven by voltages of the windings of the power transformer in order to provide the rectification of the output of the transformer. Use of synchronous rectifiers has been limited however by the inefficiency of these rectifiers in buck derived converter topologies. Efficiency is limited due to the nature of switching of buck derived converters (i.e buck, buck-boost, boost converters including forward and flyback topologies) and due to the variability of the transformer reset voltages in the forward type converters. This variability of reset voltage limits the conduction time of one of the MOSFET rectifiers, diminishing the effectiveness and efficiency of the rectifier. This is because the rectifying devices do not conduct for the full switching period and the gate drive energy of one of the rectifiers is dissipated.

## SUMMARY OF THE INVENTION

A synchronous rectifiers is combined with a clamped-mode buck derived power converter. In one illustrative embodiment a hybrid rectifier includes a MOSFET rectifying device active in a first cyclic interval of the conduction/nonconduction sequence of the power switch. A second rectifying device embodied in one illustrative embodiment as a low forward voltage drop bipolar diode rectifying device is active during an alternative interval to the first conduction/nonconduction interval. The gate drive to the MOSFET device is maintained continuous at a constant level for substantially the all of the second interval by the clamping action of the clamping circuitry of the converter. This continuous drive enhances the efficiency of the rectifier.

The bipolar rectifier device may also embodied as a MOSFET device in a rectifier using two MOSFET devices. The subject rectifier may be used in both forward and flyback power converters.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a schematic of a forward converter, of the prior art, having a synchronous rectifier;

FIG. **2** is a voltage waveform of the secondary transformer winding of the converter of FIG. **1**;

FIG. **3** is a schematic of a clamped-mode forward converter with a synchronous rectifier embodying the principles of the invention;

FIG. **4** is a voltage waveform of the secondary transformer winding of the converter of FIG. **3**;



FIG. **5** is a schematic of another version of a clamped-mode forward converter with a synchronous rectifier embodying the principles of the invention;

FIG. **6** is a schematic of another version of a clamped-mode forward converter with a synchronous rectifier and a center tapped secondary winding embodying the principles of the invention;

FIG. **7** is a schematic of a clamped-mode flyback converter with a synchronous rectifier embodying the principles of the invention; and

FIG. **8** is a schematic of another version of a clamped-mode forward converter with a synchronous rectifier and a center tapped secondary winding embodying the principles of the invention.

## DETAILED DESCRIPTION

In the converter shown in the FIG. **1**, a conventional forward topology of the prior art with an isolating power transformer is combined with a self synchronized synchronous rectifier. In such a rectifier controlled devices are used with the control terminals being driven by an output winding of the power transformer.

A DC voltage input $V_{in}$, at input **100**, is connected to the primary winding **110** of the power transformer by a MOSFET power switch **101**. The secondary winding **102** is connected to an output lead **103** through an output filter inductor **104** and a synchronous rectifier including the MOSFET rectifying devices **105** and **106**. Each rectifying device includes a body diode **108** and **107**, respectively.

With the power switch **101** conducting, the input voltage is applied across the primary winding **110**. The secondary winding **102** is oriented in polarity to respond to the primary voltage with a current flow through the inductor **104**, the load connected to output lead **103** and back through the MOSFET rectifier **106** to the secondary winding **102**. Continuity of current flow in the inductor **104**, when the power switch **101** is non-conducting, is maintained by the current path provided by the conduction of the MOSFET rectifier **105**. An output filter capacitor **111** shunts the output of the converter.

Conductivity of the MOSFET rectifiers is controlled by the gate drive signals provided by the voltage appearing across the secondary winding **102**. This voltage is shown graphically by the voltage waveform **201** in FIG. **2**. During the conduction interval $T_1$ of the power switch **101**, the secondary winding voltage $V_{ns1}$ charges the gate of MOSFET **106** to bias it conducting for the entire interval $T_1$. The MOSFET **105** is biased non conducting during the $T_1$ interval. The conducting MOSFET rectifying device **106** provides the current path allowing energy transfer to the output during the interval $T_1$. The gate of MOSFET rectifier **106** is charged in response to the input voltage $V_{in}$. All of the gate drive energy due to this voltage is dissipated.

As the power MOSFET switch **101** turns off, the voltage $V_{ns1}$ across the secondary winding **102** reverses polarity just as the time interval $T_2$ begins. This voltage reversal initiates a reset of the transformer magnetizing inductance, resonantly discharges the gate of MOSFET rectifier **106** and begins charging the gate of MOSFET rectifier **105**. As shown by the voltage waveform of FIG. **2**, the voltage across the secondary winding **102** is not a constant value, but is rather a variable voltage that collapses to zero in the subsequent time interval $T_3$, which occurs prior to the subsequent conduction interval of the power switch **101**. This voltage is operative to actually drive the rectifier **105** conducting over only a portion of the time interval $T_2$ which is

indicated by the cross hatched area **202** associated with the waveform **201** in FIG. **2**. This substantially diminishes the performance of the rectifier **105** as a low loss rectifier device. This is aggravated by the fact that the body diode **108** of the rectifier **105** has a large forward voltage drop which is too large to efficiently carry the load current.

The loss of efficiency of the synchronous rectifier limits the overall efficiency of the power converter and has an adverse effect on the possible power density attainable. Since the synchronous rectifier **105** does not continuously conduct throughout the entire switching period, a conventional rectifier diode (e.g. connected in shunt with rectifier **105**) capable of carrying the load current is required in addition to MOSFET rectifier **105**. This inefficiency is further aggravated by the gate drive energy dissipation associated with the MOSFET rectifier **106**. This gate drive loss may exceed the conduction loss for MOSFET rectifier **106**, at high switching frequency (e.g. >300 kHz).

The efficiency of a forward converter with synchronous rectification is significantly improved according to the invention by using a clamp circuit arrangement to limit the reset voltage and by using a low forward voltage drop diode in the rectifying circuitry. Such an arrangement is shown in the schematic of FIG. **3**. In this forward power converter the power MOSFET device **101** is shunted by a series connection of a clamp capacitor **321** and a MOSFET switch device **322**. The conducting intervals of power switch **101** and MOSFET device **322** are mutually exclusive. The duty cycle of power switch **101** is D and the duty cycle of MOSFET device **322** is 1-D. The voltage inertia of the capacitor **321** limits the amplitude of the reset voltage appearing across the magnetizing inductance during the non conducting interval of the MOSFET power switch **101**.

The diode **323** of the synchronous rectifier, shown in FIG. **3**, has been substituted for the MOSFET device **106** shown in the FIG. **1**. Due to the dissipation of gate drive energy the overall contribution of the MOSFET rectifier **106** in FIG. **1** is limited. The clamping action of the clamping circuitry results in the constant voltage level **402** shown in the voltage waveform **401**, across the secondary winding **102**, in the time period $T_2$. This constant voltage applied to the gate drive of the MOSFET rectifier **105** drives it into conduction for the entire $T_2$ reset interval. In this arrangement there is no need for a bipolar or a body diode shunting the MOSFET rectifier **105**. An advantage in the clamped mode converter is that the peak inverse voltage applied to the diode **323** is much less than that applied to the similarly positioned MOSFET device in FIG. **1**. Accordingly the diode **323** may be a very efficient low voltage diode which may be embodied by a low voltage diode normally considered unsuitable for rectification purposes.

In the operation of the clamped mode forward converter the MOSFET switch **322** is turned off just prior to turning the MOSFET power switch on. Energy stored in the parasitic capacitances of the MOSFET switching devices **101** and **322** is commutated to the leakage inductance of the power transformer, discharging the capacitance down toward zero voltage. During the time interval $T_3$ shown in FIG. **4**, voltage across the primary winding is supported by the leakage inductance. The voltage across the secondary winding **102** drops to zero value as shown in the FIG. **4**. With this zero voltage level of the secondary winding, the output inductor resonantly discharges the gate capacitance of the MOSFET rectifying device **105** and eventually forward biases the the bipolar diode **323**. The delay time $T_3$ is a fixed design parameter and is a factor in the control of the power switches **101** and **322**, which may be switched to accommodate soft



waveforms. This synchronous rectification circuit of FIG. **3** provides the desired efficiencies lacking in the arrangement of the circuit shown in FIG. **1**.

Control of the conductivity of the power switching devices **101** and **322** is by means of a control circuit **350**, which is connected, by lead **351**, to an output terminal **103** of the converter to sense the output terminal voltage. The control circuit **350** is connected, by leads **353** and **354**, to the drive terminals of the power switches **101** and **322**. The drive signals are controlled to regulate an the output voltage at output terminal. The exact design of a control circuit, to achieve the desired regulation, is well known in the art and hence is not disclosed in detail herein. This control circuit **350** is suitable for application to the converters of FIGS. **5**,**6**,**7** and **8**.

A modified version of the circuit of FIG. **3** is shown in the circuit schematic of the FIG.**5**. The converter of FIG. **5** is a clamped mode forward converter having two gated synchronous rectifying devices **105** and **106**. In this embodiment of the synchronous rectifier the synchronized rectifying device **106** can be used without adversely affecting the converter efficiency at lower operating frequencies.

The circuit of FIG. **6** is a clamped mode forward converter having a rectifier analogous to that of FIG. **3** in using one bipolar rectifying diode. The secondary winding is tapped creating two secondary winding segments **603** and **602**.

The converter of FIG. **7** operates in a flyback mode. The bipolar and synchronous rectifier device are in a reversed connection from the connection of FIG. **3** to accommodate the flyback operation.

In some applications direct application of the gate drive signal directly from the secondary winding may result in voltage spikes exceeding the rating of the gate. A small signal MOSFET device **813** is connected to couple the gate drive to the MOSFET rectifying device **105**. This device may be controlled by the control drive lead **815** to limit the peak voltage applied to the gate of rectifier **105**. The MOSFET synchronous rectifier is then discharged through the body diode of the MOSFET device **813**.

I claim:

**1**. In a power converter, comprising:

an input for accepting a DC voltage;

a power transformer including a primary and secondary winding;

a power switch for periodically connecting the input to the primary winding;

an output for accepting a load to be energized;

clamping means for limiting a voltage and extending the voltage's duration across the secondary winding at a substantially constant amplitude during substantially an entire extent of a clamping interval of a cyclic period of the power converter;

a rectifier connecting the secondary winding to the output; and including:

a synchronous rectification device with a control terminal connected to be responsive to signal across the secondary winding such that the synchronous rectification device conducts a load current during substantially the entire extent of the clamping interval; and

a rectifying device connected for enabling conduction of the load current during a second interval other than the clamping interval.

**2**. In a power converter, comprising

an input for accepting a DC voltage;

a power transformer including a primary and secondary winding;

a power switch for periodically connecting the input to the primary winding during a second interval of a cyclic period;

an output for accepting a load to be energized;

clamping means for limiting a voltage and extending the voltage's duration across the secondary winding at a substantially constant amplitude during substantially an entire extent of a clamping interval of a cyclic period of the power converter;

a rectifier circuit connecting the secondary winding to the output; and including:

a first synchronous rectification device with a control terminal connected to be responsive to a signal across the secondary winding such that the synchronous rectification device conducts a load current during substantially the entire extent of the clamping interval, and

a second synchronous rectification device with a control terminal connected to be responsive to a signal across the secondary winding such that the second synchronous rectification device conducts the load current during substantially an entire extent of the second interval other than the clamping interval.

**3**. In a power converter as claimed in claim **1** or **2**, comprising:

the converter connected to operate as a forward type converter.

**4**. In a power converter as claimed in claim **1** or **2**, comprising:

the converter connected to operate as a flyback type converter.

**5**. A switching mode power converter, comprising:

a power transformer including a magnetizing inductance requiring periodic recycling;

a first power stage for converting a DC input into a periodic pulsed voltage applied to primary winding of the transformer, including:

a clamping circuit for limiting a voltage of the transformer during the periodic recycling at a substantially constant amplitude and extending the voltage duration to maintain a constant voltage for substantially an entire extent of periodic recycling;

a second power stage for rectifying an output of a secondary winding of the transformer and applying it to a load to be energized, including:

a synchronous rectifier including a first rectifying device with a control gate connected to be responsive to a signal across the secondary winding such that the synchronous rectification device conducts a load current during the periodic recycling when the clamping circuit is active, and

a second rectifying device connected for enabling conduction of the load current when the first rectifying device is nonconducting.

**6**. A switching mode power converter as claimed in claim **5**, further comprising:

the second rectifying device comprises a diode.

**7**. A switching mode power converter as claimed in claim **5**, further comprising:

the second rectifying device comprises a rectifying device with a control gate connected to be responsive to a signal of the secondary winding.

**8**. A switching mode power converter as claimed in claim **6** or **7**, further comprising:

the secondary winding tapped and separated into first and second winding segments, and the first rectifying device is connected to the first winding segment and the second rectifying device is connected to the second winding segment.

**9**. A switching mode power converter as claimed in claim **6** or **7**, further comprising:

the converter connected to operate as a forward type converter.

**10**. A switching mode power converter as claimed in claim **6** or **7**, further comprising:

the converter connected to operate as a flyback type converter.

*11. A power converter, comprising:*

*a power transformer having a plurality of windings;*

*a clamping circuit, coupled to said power transformer, that limits a voltage across at least one of said plurality of windings during a clamping interval of said power converter; and*

*a synchronous rectification device coupled to said power transformer and having a control terminal responsive to a signal across at least one of said plurality of windings such that said synchronous rectification device is active for substantially all of said clamping interval.*

*12. The power converter as claimed in claim 11 wherein said clamping circuit is directly connected to said power transformer.*

*13. The power converter as claimed in claim 11 wherein said clamping circuit is coupled to a primary winding of said power transformer.*

*14. The power converter as claimed in claim 11 wherein said power transformer has a center-tapped secondary winding.*

*15. The power converter as claimed in claim 11 further comprising a power switch that connects a primary winding of said power transformer to an input of said power converter during a first cyclic interval of said power converter.*

*16. The power converter as claimed in claim 11 further comprising a further synchronous rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.*

*17. The power converter as claimed in claim 11 further comprising a rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.*

*18. The power converter as claimed in claim 11 wherein said clamping circuit comprises a switching device connected in series with a capacitor.*

*19. The power converter as claimed in claim 18 further comprising a control circuit that controls said switching device.*

*20. The power converter as claimed in claim 11 wherein said power converter operates in one of:*

*a forward mode,*

*a flyback mode, and*

*a forward/flyback mode.*

*21. A power converter, comprising:*

*a power transformer having a plurality of windings;*

*a synchronous rectification device coupled to at least one of said plurality of windings and having a control terminal; and*

*a clamping circuit, coupled to said power transformer, that limits a voltage applied to said control terminal such that said synchronous rectification device is active for substantially all of a clamping interval.*

22. The power converter as claimed in claim 21 wherein said clamping circuit is directly connected to said power transformer.

23. The power converter as claimed in claim 21 wherein said clamping circuit is coupled to a primary winding of said power transformer.

24. The power converter as claimed in claim 21 wherein said power transformer has a center-tapped secondary winding.

25. The power converter as claimed in claim 21 further comprising a power switch that connects a primary winding of said power transformer to an input of said power converter during a first cyclic interval of said power converter.

26. The power converter as claimed in claim 21 further comprising a further synchronous rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.

27. The power converter as claimed in claim 21 further comprising a rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.

28. The power converter as claimed in claim 21 wherein said clamping circuit comprises a switching device connected in series with a capacitor.

29. The power converter as claimed in claim 28 further comprising a control circuit that controls said switching device.

30. The power converter as claimed in claim 21 wherein said power converter operates in one of:

a forward mode,

a flyback mode, and

a forward/flyback mode.

31. A power converter, comprising:

a power transformer having a plurality of windings;

a synchronous rectification device having a control terminal and coupled to at least one of said plurality of windings; and

a clamping circuit, coupled to said power transformer, that limits a voltage applied to said control terminal such that said synchronous rectification device conducts a load current for substantially all of a clamping interval.

32. The power converter as claimed in claim 31 wherein said clamping circuit is directly connected to said power transformer.

33. The power converter as claimed in claim 31 wherein said clamping circuit is coupled to a primary winding of said power transformer.

34. The power converter as claimed in claim 31 wherein said power transformer has a center-tapped secondary winding.

35. The power converter as claimed in claim 31 further comprising a power switch that connects a primary winding of said power transformer to an input of said power converter during a first cyclic interval of said power converter.

36. The power converter as claimed in claim 31 further comprising a further synchronous rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.

37. The power converter as claimed in claim 31 further comprising a rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.

38. The power converter as claimed in claim 31 wherein said clamping circuit comprises a switching device connected in series with a capacitor.

39. The power converter as claimed in claim 37 further comprising a control circuit that controls said switching device.

40. The power converter as claimed in claim 31 wherein said power converter operates in one of:

a forward mode,

a flyback mode, and

a forward/flyback mode.

41. A power converter, comprising:

a power transformer having a plurality of windings;

a synchronous rectification device having a control terminal responsive to a drive signal and coupled to at least one of said plurality of windings; and

a clamping circuit, coupled to said power transformer, that limits said drive signal applied to said control terminal such that said drive signal is continuous for substantially all of a clamping interval.

42. The power converter as claimed in claim 41 wherein said clamping circuit is directly connected to said power transformer.

43. The power converter as claimed in claim 41 wherein said clamping circuit is coupled to a primary winding of said power transformer.

44. The power converter as claimed in claim 41 wherein said power transformer has a center-tapped secondary winding.

45. The power converter as claimed in claim 41 further comprising a power switch that connects a primary winding of said power transformer to an input of said power converter during a first cyclic interval of said power converter.

46. The power converter as claimed in claim 41 further comprising a further synchronous rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.

47. The power converter as claimed in claim 41 further comprising a rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.

48. The power converter as claimed in claim 41 wherein said clamping circuit comprises a switching device connected in series with a capacitor.

49. The power converter as claimed in claim 48 further comprising a control circuit that controls said switching device.

50. The power converter as claimed in claim 41 wherein said power converter operates in one of:

a forward mode,

a flyback mode, and

a forward/flyback mode.

51. A power converter, comprising:

an input that accepts a DC voltage;

an output that provides current to a load;

a power transformer having at least one primary winding and at least one secondary winding;

a power switch that periodically connects said input to said at least one primary winding during a first cyclic interval of said power converter;

a clamping circuit that limits a voltage across said at least one secondary winding during a clamping interval of said power converter; and

a synchronous rectification device having a control terminal responsive to a signal across said at least one secondary winding such that said synchronous rectification device is active for substantially all of said clamping interval.

*52. The power converter as claimed in claim 51 wherein said clamping circuit is directly connected to said power transformer.*

*53. The power converter as claimed in claim 51 wherein said clamping circuit is coupled to said at least one primary winding of said power transformer.*

*54. The power converter as claimed in claim 51 wherein said at least one secondary winding has a center-tap.*

*55. The power converter as claimed in claim 51 further comprising a voltage limiting device coupled to said synchronous rectification device.*

*56. The power converter as claimed in claim 51 further comprising a further synchronous rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.*

*57. The power converter as claimed in claim 51 further comprising a rectification device, coupled to said power*



*transformer, that is active during a first cyclic interval of said power converter.*

*58. The power converter as claimed in claim 51 wherein said clamping circuit comprises a switching device connected in series with a capacitor.*

*59. The power converter as claimed in claim 58 further comprising a control circuit that controls said switching device.*

*60. The power converter as claimed in claim 51 wherein said power converter operates in one of:*

*a forward mode,*

*a flyback mode, and*

*a forward/flyback mode.*

* * * * *

US005528482A

# United States Patent [19]

Rozman

[11] Patent Number: 5,528,482

[45] Date of Patent: *Jun. 18, 1996



[54] LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS

[75] Inventor: Allen F. Rozman, Richardson, Tex.

[73] Assignee: AT&T Corp., Murray Hill, N.J.

[*] Notice: The term of this patent shall not extend beyond the expiration date of Pat. No. 5,303,138.

[21] Appl. No.: 225,027

[22] Filed: Apr. 8, 1994

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 54,918, Apr. 29, 1993, Pat. No. 5,303,138.

[51] Int. Cl.$^6$ .......... H02M 7/217

[52] U.S. Cl. .......... 363/21; 363/20; 363/89; 327/309

[58] Field of Search .......... 363/20, 21, 89, 363/97, 126, 127

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*Primary Examiner*—Peter S. Wong
*Assistant Examiner*—Shawn Riley
*Attorney, Agent, or Firm*—Eugen E. Pacher

[57] ABSTRACT

A synchronous rectifier for use with a clamped-mode power converter uses in one embodiment a hybrid rectifier with a MOSFET rectifying device active in one first cyclic interval of the conduction/nonconduction sequence of the power switch and a second rectifying device embodied in one illustrative embodiment as a low voltage bipolar diode rectifying device active during an alternative interval to the first conduction/nonconduction interval. The gate drive to the MOSFET device is continuous at a constant level for substantially all of the second interval which enhances efficiency of the rectifier. The bipolar rectifier device may also be embodied as a MOSFET device. The subject rectifier may be used in both forward and flyback power converters.

10 Claims, 4 Drawing Sheets

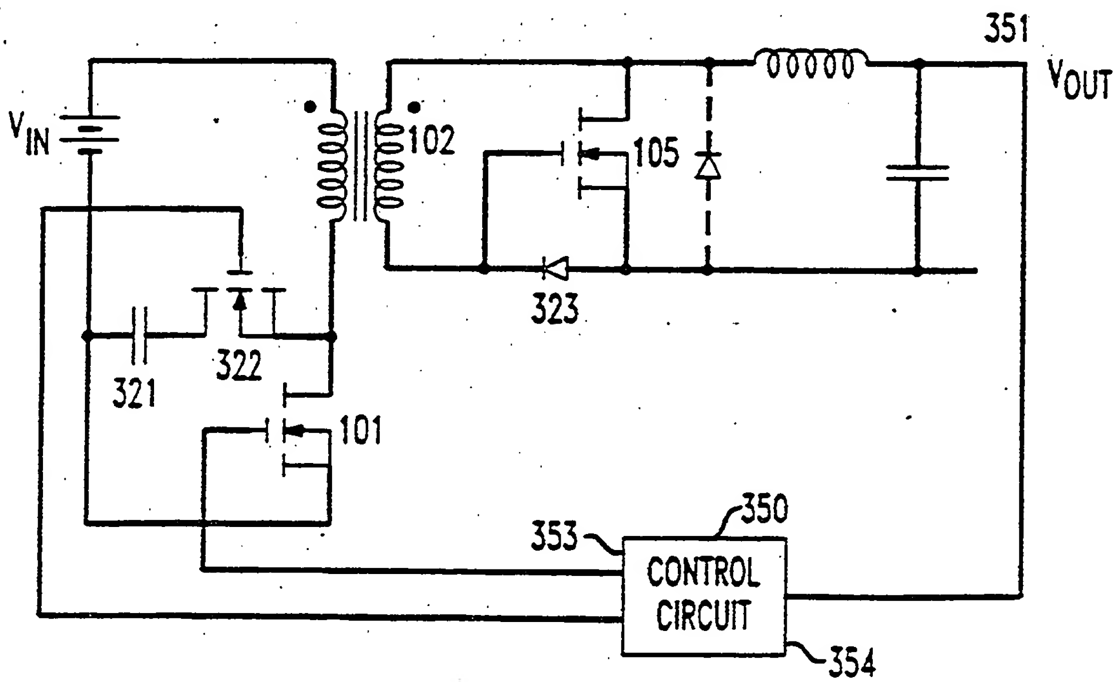


FIG. 1
(PRIOR ART)

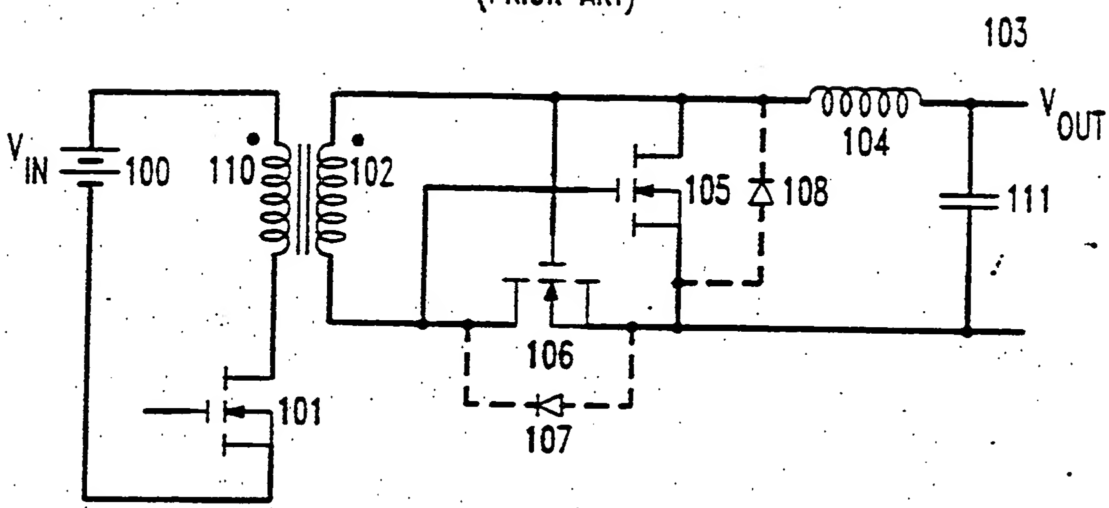



FIG. 2
(PRIOR ART)

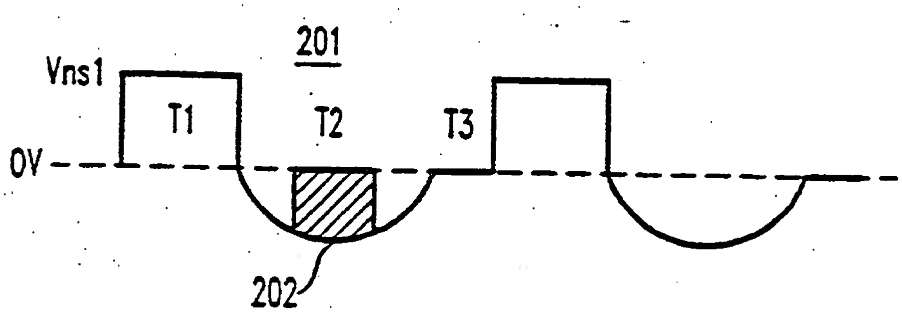


FIG. 3

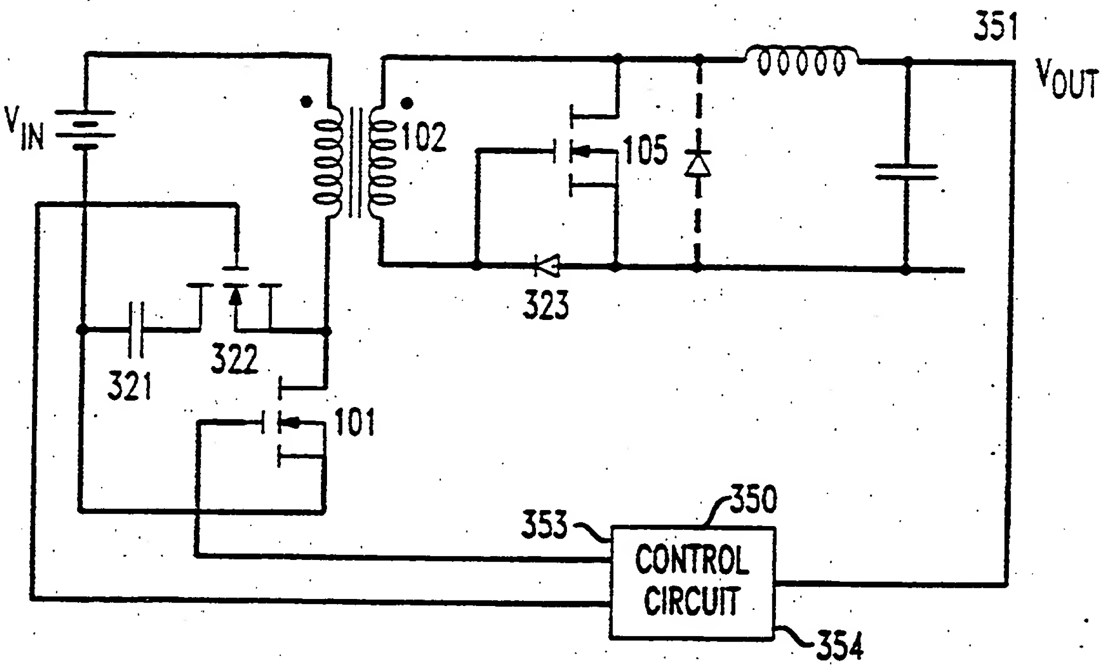

351
VOUT
VIN
102
105
323
322
321
101
350
353
CONTROL CIRCUIT
354

FIG. 4

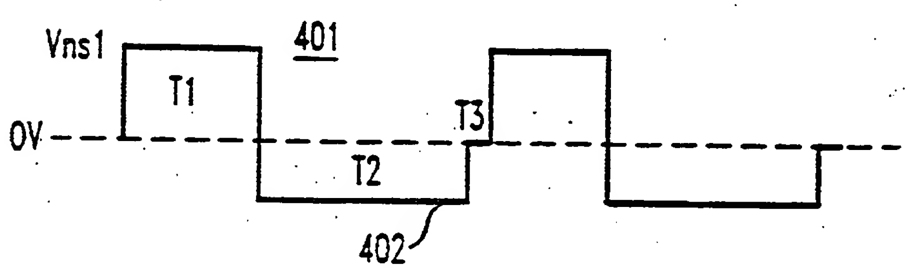

Vns1
401
T1
0V
T3
T2
402

FIG. 5

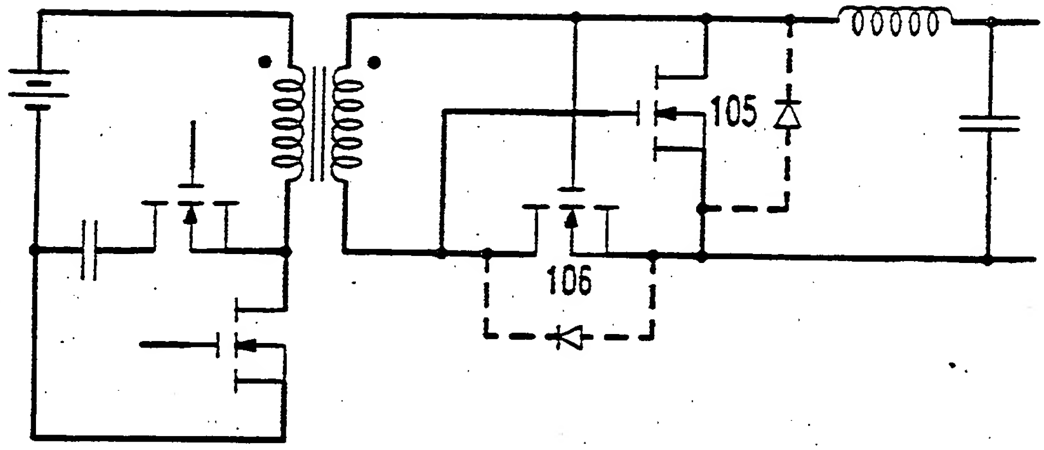



FIG. 6

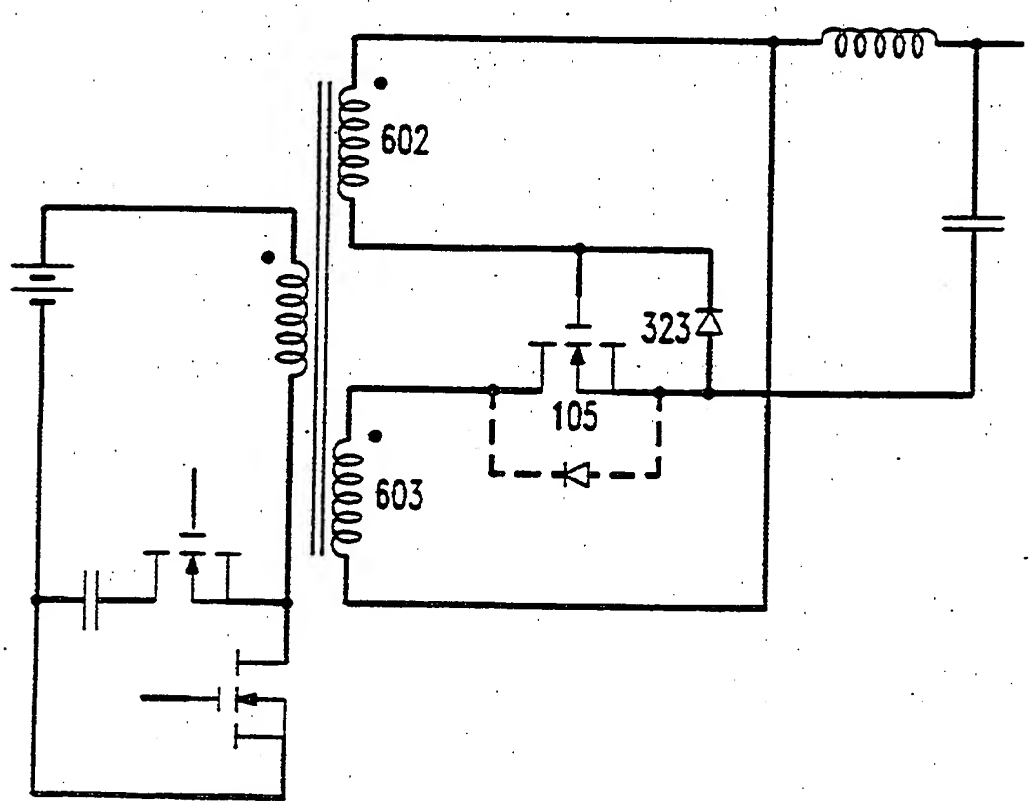


FIG. 7

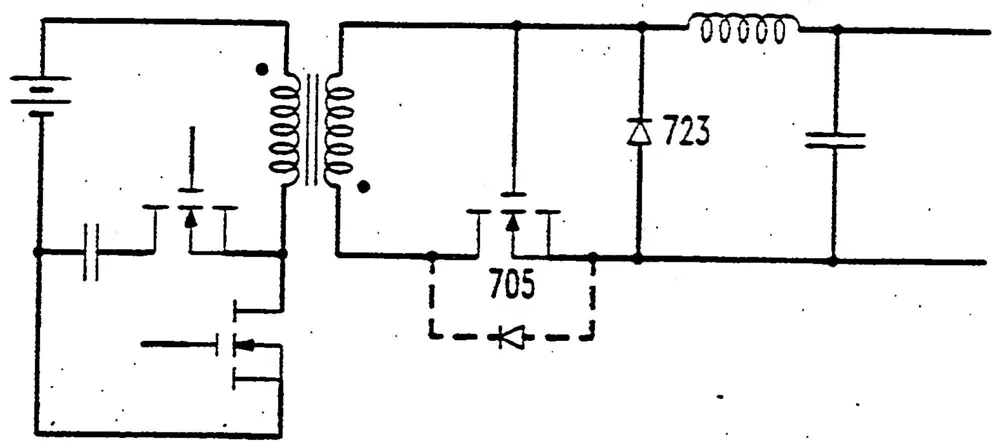
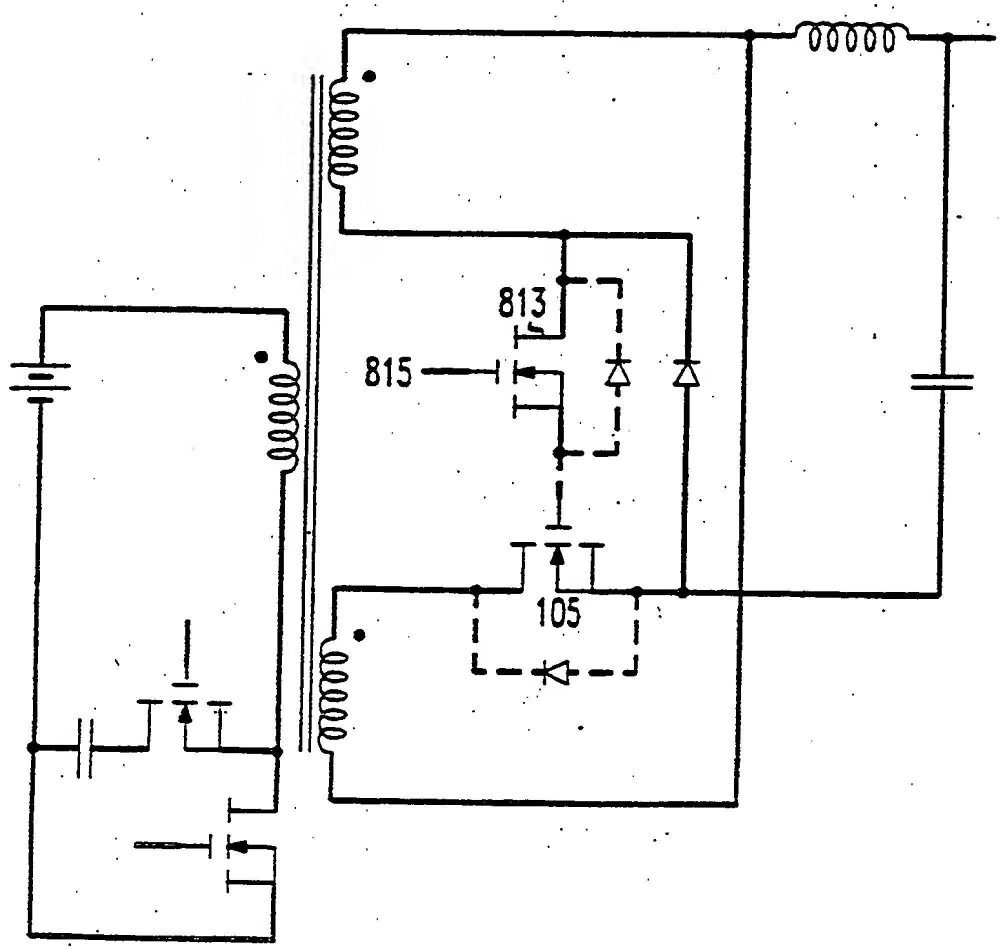



FIG. 8



# LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS

This application is a continuation in part of application Ser. No. 08/054,918 filed on Apr. 29, 1993 now issued as U.S. Pat. No. 5,303,138 on Apr. 12, 1994.

## FIELD OF THE INVENTION

This invention relates to switching type power converters and in particular to forward and flyback converters having a clamp-mode topology.

## BACKGROUND OF THE INVENTION

Self synchronized rectifiers refer to rectifiers using MOSFET rectifying devices having control terminals which are driven by voltages of the windings of the power transformer in order to provide the rectification of the output of the transformer. Use of synchronous rectifiers has been limited however by the inefficiency of these rectifiers in buck derived converter topologies. Efficiency is limited due to the nature of switching of buck derived converters (i.e buck, buck-boost, boost converters including forward and flyback topologies) and due to the variability of the transformer reset voltages in the forward type converters. This variability of reset voltage limits the conduction time of one of the MOSFET rectifiers, diminishing the effectiveness and efficiency of the rectifier. This is because the rectifying devices do not conduct for the full switching period and the gate drive energy of one of the rectifiers is dissipated.

## SUMMARY OF THE INVENTION

A synchronous rectifier is combined with a clamped-mode buck derived power converter. In one illustrative embodiment a hybrid rectifier includes a MOSFET rectifying device active in a first cyclic interval of the conduction/nonconduction sequence of the power switch. A second rectifying device embodied in one illustrative embodiment as a low forward voltage drop bipolar diode rectifying device is active during an alternative interval to the first conduction/nonconduction interval. The gate drive to the MOSFET device is maintained continuous at a constant level for substantially the all of the second interval by the clamping action of the clamping circuitry of the converter. This continuous drive enhances the efficiency of the rectifier.

The bipolar rectifier device may also embodied as a MOSFET device in a rectifier using two MOSFET devices. The subject rectifier may be used in both forward and flyback power converters.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic of a forward converter, of the prior art, having a synchronous rectifier;

FIG. 2 is a voltage waveform of the secondary transformer winding of the converter of FIG. 1;

FIG. 3 is a schematic of a clamped-mode forward converter with a synchronous rectifier embodying the principles of the invention;

FIG. 4 is a voltage waveform of the secondary transformer winding of the converter of FIG. 3;

FIG. 5 is a schematic of another version of a clamped-mode forward converter with a synchronous rectifier embodying the principles of the invention;



FIG. 6 is a schematic of another version of a clamped-mode forward converter with a synchronous rectifier and a center tapped secondary winding embodying the principles of the invention;

FIG. 7 is a schematic of a clamped-mode flyback converter with a synchronous rectifier embodying the principles of the invention; and

FIG. 8 is a schematic of another version of a clamped-mode forward converter with a synchronous rectifier and a center tapped secondary winding embodying the principles of the invention.

## DETAILED DESCRIPTION

In the converter shown in the FIG. 1, a conventional forward topology of the prior art with an isolating power transformer is combined with a self synchronized synchronous rectifier. In such a rectifier controlled devices are used with the control terminals being driven by an output winding of the power transformer.

A DC voltage input $V_{in}$, at input **100**, is connected to the primary winding **110** of the power transformer by a MOSFET power switch **101**. The secondary winding **102** is connected to an output lead **103** through an output filter inductor **104** and a synchronous rectifier including the MOSFET rectifying devices **105** and **106**. Each rectifying device includes a body diode **108** and **107**, respectively.

With the power switch **101** conducting, the input voltage is applied across the primary winding **110**. The secondary winding **102** is oriented in polarity to respond to the primary voltage with a current flow through the inductor **104**, the load connected to output lead **103** and back through the MOSFET rectifier **106** to the secondary winding **102**. Continuity of current flow in the inductor **104**, when the power switch **101** is non-conducting, is maintained by the current path provided by the conduction of the MOSFET rectifier **105**. An output filter capacitor **111** shunts the output of the converter.

Conductivity of the MOSFET rectifiers is controlled by the gate drive signals provided by the voltage appearing across the secondary winding **102**. This voltage is shown graphically by the voltage waveform **201** in FIG. 2. During the conduction interval $T_1$ of the power switch **101**, the secondary winding voltage $V_{ns1}$ charges the gate of MOSFET **106** to bias it conducting for the entire interval $T_1$. The MOSFET **105** is biased non conducting during the $T_1$ interval. The conducting MOSFET rectifying device **106** provides the current path allowing energy transfer to the output during the interval $T_1$. The gate of MOSFET rectifier **106** is charged in response to the input voltage $V_{in}$. All of the gate drive energy due to this voltage is dissipated.

As the power MOSFET switch **101** turns off, the voltage $V_{ns1}$ across the secondary winding **102** reverses polarity just as the time interval $T_2$ begins. This voltage reversal initiates a reset of the transformer magnetizing inductance, resonantly discharges the gate of MOSFET rectifier **106** and begins charging the gate of MOSFET rectifier **105**. As shown by the voltage waveform of FIG. 2, the voltage across the secondary winding **102** is not a constant value, but is rather a variable voltage that collapses to zero in the subsequent time interval $T_3$, which occurs prior to the subsequent conduction interval of the power switch **101**. This voltage is operative to actually drive the rectifier **105** conducting over only a portion of the time interval $T_2$ which is indicated by the cross hatched area **202** associated with the waveform **201** in FIG. 2. This substantially diminishes the

performance of the rectifier 105 as a low loss rectifier device. This is aggravated by the fact that the body diode 108 of the rectifier 105 has a large forward voltage drop which is too large to efficiently carry the load current.

The loss of efficiency of the synchronous rectifier limits the overall efficiency of the power converter and has an adverse effect on the possible power density attainable. Since the synchronous rectifier 105 does not continuously conduct throughout the entire switching period, a conventional rectifier diode (e.g. connected in shunt with rectifier 105) capable of carrying the load current is required in addition to MOSFET rectifier 105. This inefficiency is further aggravated by the gate drive energy dissipation associated with the MOSFET rectifier 106. This gate drive loss may exceed the conduction loss for MOSFET rectifier 106, at high switching frequency (e.g. >300 kHz).

The efficiency of a forward converter with synchronous rectification is significantly improved according to the invention by using a clamp circuit arrangement to limit the reset voltage and by using a low forward voltage drop diode in the rectifying circuitry. Such an arrangement is shown in the schematic of FIG. 3. In this forward power converter the power MOSFET device 101 is shunted by a series connection of a clamp capacitor 321 and a MOSFET switch device 322. The conducting intervals of power switch 101 and MOSFET device 322 are mutually exclusive. The duty cycle of power switch 101 is D and the duty cycle of MOSFET device 322 is 1-D. The voltage inertia of the capacitor 321 limits the amplitude of the reset voltage appearing across the magnetizing inductance during the non conducting interval of the MOSFET power switch 101.

The diode 323 of the synchronous rectifier, shown in FIG. 3, has been substituted for the MOSFET device 106 shown in the FIG. 1. Due to the dissipation of gate drive energy the overall contribution of the MOSFET rectifier 106 in FIG. 1 is limited. The clamping action of the clamping circuitry results in the constant voltage level 402 shown in the voltage waveform 401, across the secondary winding 102, in the time period $T_2$. This constant voltage applied to the gate drive of the MOSFET rectifier 105 drives it into conduction for the entire $T_2$ reset interval. In this arrangement there is no need for a bipolar or a body diode shunting the MOSFET rectifier 105. An advantage in the clamped mode converter is that the peak inverse voltage applied to the diode 323 is much less than that applied to the similarly positioned MOSFET device in FIG. 1. Accordingly the diode 323 may be a very efficient low voltage diode which may be embodied by a low voltage diode normally considered unsuitable for rectification purposes.

In the operation of the clamped mode forward converter the MOSFET switch 322 is turned off just prior to turning the MOSFET power switch on. Energy stored in the parasitic capacitances of the MOSFET switching devices 101 and 322 is commutated to the leakage inductance of the power transformer, discharging the capacitance down toward zero voltage. During the time interval $T_3$ shown in FIG. 4, voltage across the primary winding is supported by the leakage inductance. The voltage across the secondary winding 102 drops to zero value as shown in the FIG. 4. With this zero voltage level of the secondary winding, the output inductor resonantly discharges the gate capacitance of the MOSFET rectifying device 105 and eventually forward biases the the bipolar diode 323. The delay time $T_3$ is a fixed design parameter and is a factor in the control of the power switches 101 and 322, which may be switched to accommodate soft waveforms. This synchronous rectification circuit of FIG. 3 provides the desired efficiencies lacking in the arrangement of the circuit shown in FIG. 1.



Control of the conductivity of the power switching devices 101 and 322 is by means of a control circuit 350, which is connected, by lead 351, to an output terminal 103 of the converter to sense the output terminal voltage. The control circuit 350 is connected, by leads 353 and 354, to the drive terminals of the power switches 101 and 322. The drive signals are controlled to regulate an the output voltage at output terminal. The exact design of a control circuit, to achieve the desired regulation, is well known in the art and hence is not disclosed in detail herein. This control circuit 350 is suitable for application to the converters of FIGS. 5,6,7 and 8.

A modified version of the circuit of FIG. 3 is shown in the circuit schematic of the FIG.5. The converter of FIG. 5 is a clamped mode forward converter having two gated synchronous rectifying devices 105 and 106. In this embodiment of the synchronous rectifier the synchronized rectifying device 106 can be used without adversely affecting the converter efficiency at lower operating frequencies.

The circuit of FIG. 6 is a clamped mode forward converter having a rectifier analogous to that of FIG. 3 in using one bipolar rectifying diode. The secondary winding is tapped creating two secondary winding segments 603 and 602.

The converter of FIG. 7 operates in a flyback mode. The bipolar and synchronous rectifier device are in a reversed connection from the connection of FIG. 3 to accommodate the flyback operation.

In some applications direct application of the gate drive signal directly from the secondary winding may result in voltage spikes exceeding the rating of the gate. A small signal MOSFET device 813 is connected to couple the gate drive to the MOSFET rectifying device 105. This device may be controlled by the control drive lead 815 to limit the peak voltage applied to the gate of rectifier 105. The MOSFET synchronous rectifier is then discharged through the body diode of the MOSFET device 813.

I claim:

1. In a power converter, comprising:

an input for accepting a DC voltage;

a power transformer including a primary and secondary winding;

a power switch for periodically connecting the input to the primary winding;

an output for accepting a load to be energized;

clamping means for limiting a voltage and extending the voltage's duration across the secondary winding at a substantially constant amplitude during substantially an entire extent of a clamping interval of a cyclic period of the power converter;

a rectifier circuit connecting the secondary winding to the output; and including:

a synchronous rectification device with a control terminal connected to be responsive to a signal across the secondary winding such that the synchronous rectification device conducts a load current during substantially the entire extent of the clamping interval; and

a rectifying device connected for enabling conduction of the load current during a second interval other than the clamping interval.

2. In a power converter, comprising

an input for accepting a DC voltage;

a power transformer including a primary and secondary winding;

a power switch for periodically connecting the input to the primary winding during a second interval of a cyclic period;

an output for accepting a load to be energized;

clamping means for limiting a voltage and extending the voltage's duration across the secondary winding at a substantially constant amplitude during substantially an entire extent of a clamping interval of a cyclic period of the power converter;

a rectifier circuit connecting the secondary winding to the output; and including:

a first synchronous rectification device with a control terminal connected to be responsive to a signal across the secondary winding such that the synchronous rectification device conducts a load current during substantially the entire extent of the clamping interval, and

a second synchronous rectification device with a control terminal connected to be responsive to a signal across the secondary winding such that the second synchronous rectification device conducts the load current during substantially an entire extent of the second interval other than the clamping interval.

3. In a power converter as claimed in claim 1 or 2, comprising:

the converter connected to operate as a forward type converter.

4. In a power converter as claimed in claim 1 or 2, comprising:

the converter connected to operate as a flyback type converter.

5. A switching mode power converter, comprising:

a power transformer including a magnetizing inductance requiring periodic recycling;

a first power stage for converting a DC input into a periodic pulsed voltage applied to a primary winding of the transformer, including:

a clamping circuit for limiting a voltage of the transformer during the periodic recycling at a substantially constant amplitude and extending the voltage duration to maintain a constant voltage for substantially an entire extent of periodic recycling;



a second power stage for rectifying an output of a secondary winding of the transformer and applying it to a load to be energized, including:

a synchronous rectifier including a first rectifying device with a control gate connected to be responsive to a signal across the secondary winding such that the synchronous rectification device conducts a load current during the periodic recycling when the clamping circuit is active, and

a second rectifying device connected for enabling conduction of the load current when the first rectifying device is nonconducting.

6. A switching mode power converter as claimed in claim 5, further comprising:

the second rectifying device comprises a diode.

7. A switching mode power converter as claimed in claim 5, further comprising:

the second rectifying device comprises a rectifying device with a control gate connected to be responsive to a signal of the secondary winding.

8. A switching mode power converter as claimed in claim 6 or 7, further comprising:

the secondary winding tapped and separated into first and second winding segments, and the first rectifying device is connected to the first winding segment and the second rectifying device is connected to the second winding segment.

9. A switching mode power converter as claimed in claim 6 or 7, further comprising:

the converter connected to operate as a forward type converter.

10. A switching mode power converter as claimed in claim 6 or 7, further comprising:

the converter connected to operate as a flyback type converter.

* * * * *